Importance of Thin Plankton Layers in Hawaiian Food Web Interactions: Research Spanning From Physical Circulation to Spinner Dolphins

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LONG-TERM GOAL

Our long-term goal is to develop the capability to predict the occurrence and consequences of layer structure and biological aggregations in coastal waters.

OBJECTIVES

Our goals are (1) to quantify layered aggregations of the *phytoplankton, zooplankton, and the nearshore sound-scattering layer* around Hawaii, (2) to identify the physical, optical, and acoustical characteristics associated with these aggregations, (3) to assess the horizontal scales of coherence between these various levels of biological aggregations and understand their interactions, (4) to assess the impact of these layers on optical and acoustical measurements in the nearshore environment, (5) to determine the effects of layered aggregations on *spinner dolphins*.

APPROACH

This project takes an interdisciplinary approach to look at the relationships between the distribution of phytoplankton, zooplankton, mesopelagic micronekton, and spinner dolphins along with acoustical and optical scattering from these organisms, as well as the bathymetry and physical circulation patterns of the study region. We combine moored and expeditionary approaches to determine the predictors of organismal distribution and the relationship between various groups. The system presents a unique opportunity to look at how the organisms in Hawaii’s nearshore waters aggregate and disassemble as

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Importance of Thin Plankton Layers in Hawaiian Food Web Interactions: Research Spanning From Physical Circulation to Spinner Dolphins**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Oregon State University,College of Oceanic and Atmospheric Sciences,104 COAS Administration Building,Corvallis,OR,97331-5503**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

many of the biological mechanisms are regulated on a diel cycle as a response to light levels. The study area extends west of the leeward coast of Oahu, Hawaii. This area was chosen because of the high abundance of spinner dolphins, the presence of dense aggregations of thin layers and micronekton.

WORK COMPLETED

Mooring Array. For approximately 5 weeks (April 20 to May 27) in 2005, 5 weeks (April 9 to May 16) in 2006, 3 weeks (20 April to 11 May) in 2009, and 3 weeks (9 April to 30 April) in 2010, a series of moorings were deployed to assess the biological, chemical and physical features off Oahu's leeward coast in addition to the optical and acoustical characteristics of the water column. **Shipboard Surveys.** To further characterize the location of the sound-scattering layer, thin layers, spinner dolphins, hydrography and optical properties in 3-dimensions; we used a small vessel (30 ft) to conduct 24-hour continuous profiles during each of these studies. In total, four shipboard surveys were undertaken in 2005; three, 24-hour shipboard surveys were undertaken in 2006; three, 24-hour shipboard surveys were undertaken in 2009 and three, 24-hour shipboard surveys were undertaken in 2010 each in synch with the phases of the moon. **Data Analyses**. Our data from 2005, 2006, 2009 and 2010 have been processed. We are in the process of (1) quantifying layered aggregations of the phytoplankton, zooplankton, and the nearshore sound-scattering layer, (2) identifying the physical, optical, and acoustical characteristics associated with these aggregations, (3) assessing the horizontal scales of coherence between these various levels of biological aggregations and understand their interactions, (4) assessing the impact of these layers on optical and acoustical measurements in the nearshore environment, (5) determining the effects of thin layers on spinner dolphins.

RESULTS

Thus far, eight publications have resulted from our fieldwork in 2005, 2006, 2009 and 2010 (Benoit-Bird et al. 2008, McManus et al. 2008, Benoit-Bird 2009, Benoit-Bird et al 2009a, Benoit-Bird et al. 2009b, Sevadjian et al. 2010, McManus et al. in revision, Sevadjian et al. in revision)

We are continuing our analysis of existing individual data sets, and our synthesis of physical, optical and acoustical data for the Hawaiian Islands in the following subject areas:

1. Bottom-up regulation of a pelagic community through aggregations - not biomass
2. Periodic alterations of nearshore optical and acoustical scatting caused by tidally driven, near bottom cold-pulses
3. The effects of layered aggregations of plankton on diel vertical migration
4. Interannual comparison of the effects of environmental change on patchiness in the coastal ocean

Bottom-up regulation of a pelagic community through aggregations - not biomass

We are examining the relationships among four trophic levels that are found in distinct, extreme aggregations to examine the relative importance of biomass and patchiness in the regulation of a pelagic marine food web. We find that the number and intensity of aggregations, rather than total biomass, in each step of a food chain involving phytoplankton, copepods, mesopelagic micronekton, and spinner dolphins (*Stenella longirostris*) were the most significant predictors of variation in adjacent trophic levels. Our results are in accordance with resource limitation - mediated by patchiness - regulating structure at each trophic step in this ecosystem, as well as the behaviour of the top predator. The importance of spatial pattern in ecosystems has long been recognized and its effects on predator-prey pairs have been examined in a number of studies; however, our results indicate that patchiness may be the *dominant* force regulating an entire system. Additional analyses are needed to address the energetic-coupling between each of the four trophic levels.

Periodic alterations of nearshore optical and acoustical scatting caused by tidally driven, near bottom cold-pulses

We observe periodic pulses of cold, high salinity water in the near bottom temperature and salinity records of our moorings. These 'cold pulses' were associated with up to 2°C drops in the local water temperature. Close examination of the observed pulses revealed that they were stronger on or near spring tides, and very predictable.

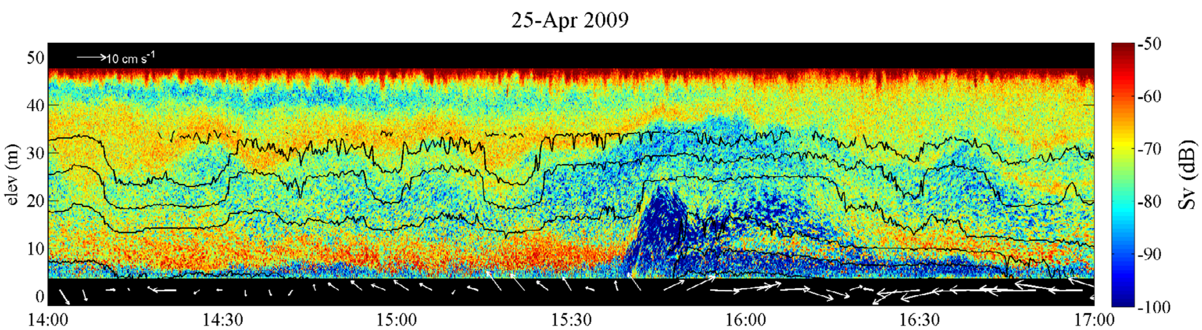

Figure 1. Time series of acoustic scattering (colorbar), temperature (isotherms are in 0.5 degree C increments), and bottom currents (white arrows scale on upper left hand side of figure 2), from the leeward coast of Oahu, Hawaii in the area of 21° 30.5' N, 158° 14.2' W.

We have quantified these events, and examined how these events change stratification, current flow, and nutrients, as well as the optical and acoustical signal in the water column. An example of one cold-pulse event is shown in Figure 1. These cold-pulse events result in an increase in near-bottom stratification, a shift in near-bottom currents, an increase in nutrients, a shift in the phytoplankton population (as confirmed by bottle samples) and a movement of strong scatterers off the seafloor, an accumulation of scatterers at the density gradient associated with the cold pulse and a lack of scattering within the cold pulse. It is interesting to note, that the total integrated water column scattering, a measure of the total abundance of scatterers 10 minutes before and 10 minutes after the onset of the cold pulse were not statistically different. This analysis has been submitted to Limnology and Oceanography in a manuscript entitled "Planktonic responses to episodic near-bottom water pulses in tropical waters" Sevadjian JC, MA McManus, KJ Benoit-Bird, KE Selph.

It is important to note that physical oceanographic evidence of similar cold bottom pulses have recently been observed at island sites throughout the ~north Pacific basin, spanning a latitudinal gradient of 28.12^{o} (Pearl and Hermes Atoll (27.9°N, 167.8°W), Wake Atoll (19°N, 166°E), Palmyra Atoll (5.9°N, 162°W), and Jarvis Island (0.22°S, 160°W) – Gove and McManus unpubl. data). These widespread observations suggest that this unquantified phenomenon extends across most of the Pacific basin.

The effects of layered aggregations of plankton on diel vertical migration

Comparison of the depth of micronekton layers when thin zooplankton layers were detected versus when they were absent showed that micronekton remained deeper when thin zooplankton layers were formed. This change in depth keeping behavior represents, on average, 20% of the entire water column and swamps changes observed in micronekton depth due to lunar phase and other well recognized cues affecting vertical migration (Figure 2).

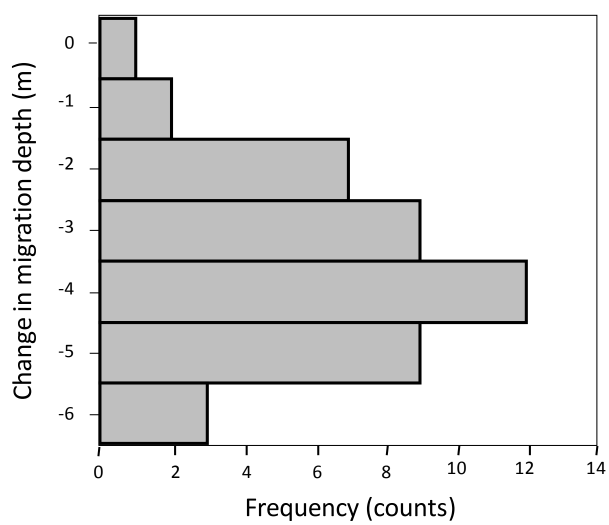

Figure 2. The change in migration depth of the micronekton depth in 20 m of water when thin layers were present relative to when layers were absent. Micronekton abbreviate their vertical migration in shallow water by an average of 20% of the water column when dense, thin aggregations of zooplankton are present.

We are in the process of quantifying how this abbreviation in micronekton vertical migration is affected by changes in the characteristics of zooplankton thin layers such as density and species composition. These changes in micronekton depth change the accessibility of these animals to spinner dolphins. We are currently examining if these changes have significant consequences for the foraging behavior of spinner dolphins and if so, what the potential population level consequences are.

Interannual comparison of the effects of environmental change on patchiness in the coastal ocean

It is well documented that human activities are changing the Earth's atmosphere. Levels of greenhouse gases, like carbon dioxide (CO_2), have increased in the last 50 years. While scientific findings indicate that rising levels of greenhouse gases are contributing to climate change, important questions remain about how much more warming will occur and at what rate, and how the warming will affect the rest of the climate system including changes in wind fields, precipitation patterns and storms. These changes to the climate system drive changes in the ocean system, which in turn affect coastal marine ecosystems.

By using historical data, like those data sets we've collected off the west shore of Oahu in 2005, 2006, 2009 and 2010, we are striving to identify how four trophic levels respond to a variable environment. It should be noted that 2010 was classified as a strong El Nino year, in Hawaii we experienced colder than normal temperatures, lower precipitation and stronger winds. These physical changes had direct effects on the planktonic system. In particular, the optical and acoustical scattering signals in 2010 were very different from the three prior years.

Our goal is to produce a better understanding of how the planktonic system responds to longer-term (yearlong) shifts in temperature, precipitation and wind fields. This critical information will provide the foundation for more accurate predictions of how the marine system will respond in the future as our climate changes.

IMPACT/APPLICATIONS

This research combines work in acoustics, optics, and physical oceanography to understand the role thin plankton layers play in structuring trophic interactions in Hawaii's nearshore ecosystem. This understanding of predators' use of thin layers will provide insight into the processes driving the formation, maintenance, and dissipation of thin layers of both phytoplankton and zooplankton. It will also permit us to look at the indirect effects of zooplankton thin layers on the foraging behavior of spinner dolphins through effects on their micronekton prey. We are addressing the relationship between these significant biological sources of scattering and the acoustical, optical, and physical characteristics of the water column. We are determining which physical and biological measures can be used to make predictions about the distribution of phytoplankton, zooplankton, micronekton, and spinner dolphins.

The ability to predict biological sources of scattering will provide significant information for the interpretation of tactical acoustic and optical instruments. In addition, management of marine mammal species and mitigation of human impacts on dolphin populations must be done with an understanding of the ecosystem forces driving their behavior.

This work takes an unprecedented look at the fine scale, subsurface ecology of dolphins along with a detailed examination of their physical and biological environment, providing substantial information to guide mitigation efforts. This is the first fully integrated ecosystem study of thin layers and their ecological significance.

RELATED PROJECTS

Funding Agency: Office of Naval Research

Project Title: Quantification of the Interacting Physical, Biological, Optical and Chemical Properties of Thin Layers in the Sea

Project Period: 02/2004-12/2009

Principal Investigators: PI Margaret McManus (UH); Co-PIs John Ryan (MBARI), Mark Stacey (Berkeley)

PUBLICATIONS DIRECTLY RELATED TO THIS WORK

2008

(1) Benoit Bird KJ, MJ Zirbel, MA McManus (2008) Diel variation of zooplankton distribution in Hawaiian waters favors horizontal diel migration by midwater micronekton. Mar Ecol Prog Ser. 367:109-123. [published, refereed]

(2) McManus MA, KJ Benoit-Bird, CB Woodson (2008) Behavior Exceeds Physical Forcing in the Diel Horizontal Migration of a Midwater Sound-Scattering Layer in Hawaiian Waters. Mar Ecol Prog Ser. 365: 91-101. [published, refereed]

2009

(3) Benoit-Bird, K.J. (2009) Effects of scattering layer composition, animal size, and numerical density on the frequency response of volume backscatter. ICES Journal of Marine Science, 66: 582-593. [published, refereed]

(4) Benoit-Bird, K.J., Au, W.W.L., Wisdom, D.W.* (2009) Nocturnal light and lunar cycle effects on diel migration of micronekton. Limnol Oceanogr 54: 1789-1800. [published, refereed]

(5) Benoit-Bird, K.J., Dahood, AD, & Wursig, B (2009) "Using active acoustics to compare predator-prey behavior of two marine mammal species". Invited Contribution to Special Issue "Applications of Acoustics in Exploring Marine Ecosystems and the Impacts of Anthropogenic Sound" Marine Ecology Progress Series 395: 119–135. [published, refereed]

2010

(6) Sevadjian JC, McManus MA, Pawlak G (2010) Effects of physical structure and processes on thin zooplankton layers in Mamala Bay, Hawaii. Mar Ecol Prog Ser 409:95-106. [published, refereed]

Submitted

(7) McManus MA, JC Sevadjian, KJ Benoit-Bird, OM Cheriton, AV Timmerman, CM Waluk. submitted. Observations of thin layers in coastal Hawaiian waters. *Estuaries and Coasts.* [in revision]

(8) Sevadjian JC, MA McManus, KJ Benoit-Bird, KE Selph. submitted. Planktonic responses to episodic near-bottom water pulses in tropical waters. *Limnology and Oceanography* [in revision]

HONORS/AWARDS/PRIZES

Kelly Benoit-Bird, Oregon State University

- Kavli Frontiers Fellow, National Academy of Sciences, 2006
- Presidential Early Career Award for Scientists and Engineers, 2006
- Ocean Sciences Early Career Award, American Geophysical Union, 2008 for *"innovative application of acoustical techniques"*

- Promotion to Associate Professor, 2009
- R. Bruce Lindsay Award, Acoustical Society of America, 2009 for *“contributions to marine ecological acoustics”*
- Best Presentation Award (for presentation of results of this work), Pacific Marine Science Organization (PICES) Committee on Monitoring, 2009
- MacArthur Fellowship for "exceptional creativity and promise for important future advances based on a track record of significant accomplishment", 2010

Margaret McManus, University of Hawaii at Manoa,

- Aldo Leopold Fellow, 2006
- Promotion to Associate Professor with Tenure, 2007
- Kavli Frontiers Fellow, National Academy of Sciences, 2009